REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
Unclassified	

2a. SECURITY CLASSIFICATION AUTHORITY

DTIC ELECTE NOV 2 3 1988

AD-A202 252

ER(S) H

3. DISTRIBUTION / AVAILABILITY OF REPORT

Approved for public release;
distribution unlimited.

5. MONITORING ORGANIZATION REPORT NUMBER(S)

ARO 22851.1-GS

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Univ. of Massachusetts		U. S. Army Research Office

6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code)
Amherst, MA 01002	P. O. Box 12211 Research Triangle Park, NC 27709-2211

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
U. S. Army Research Office		DAAG29-85-K-0227

8c. ADDRESS (City, State, and ZIP Code)

P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Normalized Radar Cross Section of Natural Surfaces at Millimeter Wavelengths

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 9/23/85 TO 9/22/85	November 1988	8

16. SUPPLEMENTARY NOTATION

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Millimeter Waves, Remote Sensing, Radar Systems, Electromagnetic Signals, Radar Backscatter, Snow-Covered Surfaces

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The scattering of millimeter waves by foliated and snow-covered surfaces is of interest to designers of future radar and communication systems. It is also of interest to the remote sensing community, which is interested in the high-frequency behavior of radar signatures of natural surfaces. The University of Massachusetts Microwave Remote Sensing Laboratory developed a unique high-powered 215 GHz radar system.

It used this system to measure the Normalized Radar Cross Section (NRCS) of trees and snow packs. Results of these studies are described in this report.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Microwave and Electronics

Electrical and Computer Engineering

University of Massachusetts at Amherst

88 1122 07

FINAL TECHNICAL REPORT
Research Contract DAAG29-85-K-0227

Research Conducted

by

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U.S. Army Research Office
Research Triangle Park, NC

November 1988

1. Forward

The scattering of millimeter waves by foliated and snow-covered surfaces is of interest to designers of future radar and communication systems. It is also of interest to the remote sensing community, which is interested in the high-frequency behavior of radar signatures of natural surfaces. The University of Massachusetts Microwave Remote Sensing Laboratory developed a unique high-powered 215 GHz radar system as part of the research carried out under ARO contract DAAG29-85-K-0227. It used this system to measure the Normalized Radar Cross Section (NRCS) of trees and snow packs. Results of these studies are described below.

2. Table of Contents

3. List of Appendices

Not Applicable

4. Body of Report

A. STATEMENT OF PROBLEM

Very little is known about the transmission and scattering of 215 GHz electromagnetic signals because few systems have been developed that can operate at that frequency. Recent developments of high power sources and receivers, however, suggest that radar

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systems are feasible at 215 GHz. The research conducted under ARO Grant DAAG29-85-K-0227 was aimed at determining ground clutter effects at 215 GHz.

B. MOST IMPORTANT RESULTS

(1) Development of 215 GHz Radar System

A 215 GHz incoherent radar, originally fabricated by Norden Systems of United Technologies and provided to the U.S. Army–Night Visions Laboratory, was refurbished by the MIRSL. The design and performance of this radar system is described in [1], which is listed in 4C. The electrical characteristics of the 215 GHz system is summarized in Table I below:

Table 1

Characteristics of UMass 215 GHz Radar System

Transmitter

Center Frequency	215 GHz Nominal
Peak Output Power	60W
Pulsewidth	100 nsec
PRF	2/10 KHz Internal
	700 Hz – 20 KHz External
Tuning Bandwidth	300 MHz

Antennas

	Lens	Horn
3 dB beamwidth	0.64 deg	23 deg
Directivity	49.6 dB	18.5 dB

Receiver

Noise Figure	10 dB DSB
1st IF	1.4 GHz
2nd IF	160 MHz
Bandwidth	300 MHz, 1st IF
	40 MHz, 2nd IF
Dynamic Range	70 dB

System

Polarization	Linear HH, HV, VH, VV
Operating Mode	Monostatic or Bistatic
Positioning	Azimuth and Elevation

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The advent of high-power extended interactions oscillators and low-noise receivers in the 215 GHz frequency window makes it possible to design and operate radar systems at these wavelengths. The UMass high-power 215 GHz pulsed radar system is capable of making calibrated backscatter measurements from terrain targets at ranges of several kilometers under normal atmospheric conditions.

(2) Radar Backscatter Measurements of Trees at 215 GHz

We used the radar described above to make millimeter-wave backscatter measurements of various tree types during the 1987 growing season at Amherst, Massachusetts. These measurements are described in [2], which is listed in 4c below. The n rmalized radar cross section (NRCS) of a black oak and a white pine tree are shown below. Also measured were ground truth measurements of the normalized leaf area, gravitational leaf water content and the percentage of leaf coverage for all trees in the study.
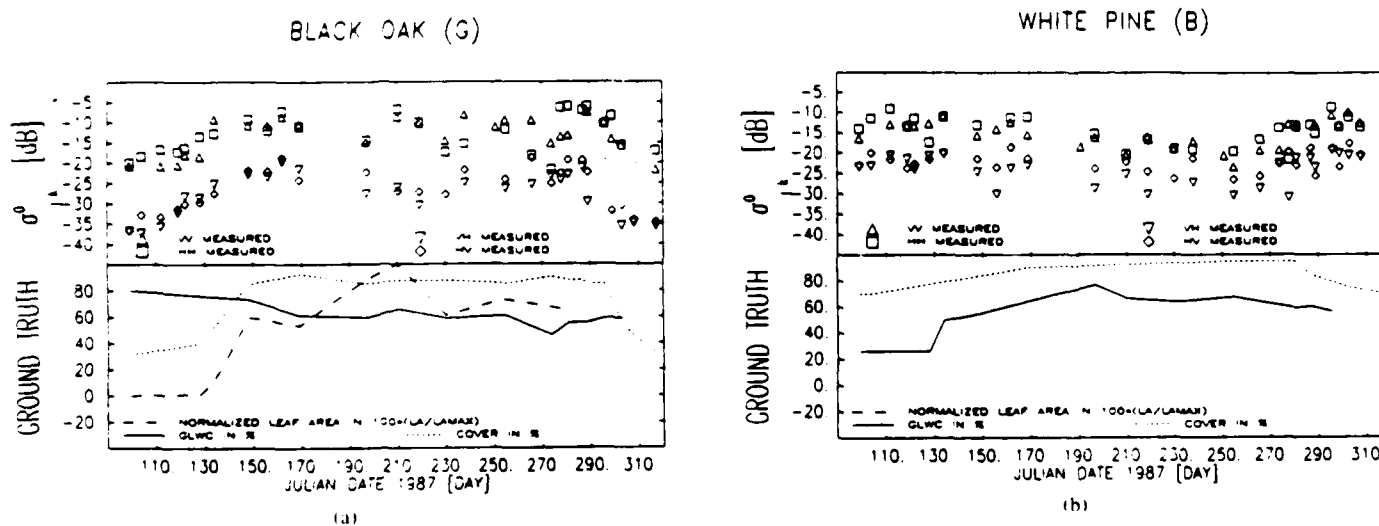
BLACK OAK (G)   WHITE PINE (B)

Fig. 1   NRCS measurements of black oak and white pine trees during 1987 foliation season.

The NRCS was obtained for VV, HH, HV and VH polarization for 17 different trees and tree groups. A summary of like-pol NRCS values averaged over the entire growing season is shown in Table II.

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Table II.

Comparison of NRCS of Planophil versus Erectophil Trees Near Horizontal Incidence

Tree	Code*	Tree Type	$\langle \sigma^\circ_{VV} \rangle$ dB(m²·m⁻²)	$\langle \sigma^\circ_{HH} \rangle$ dB(m²·m⁻²)	Difference Between VV and HH Measurements $\langle \sigma^\circ_{VV} \rangle - \langle \sigma^\circ_{HH} \rangle$ dB	Average of VV and HH Measurements dB(m²·m⁻²)
1. Red Maple (*Acer Rubrum*)	N	Planophil	-17.1	-16.3	+.8	16.7
2. Silver Maple (*Acer Saccharinum*)	H	Planophil	-12.6	-12.1	+.5	-12.4
3. Sugar Maple (*Acer Saccharum*)	D	Planophil	-12.9	-10.3	+2.6	-11.6
4. Black Oak (*Quercus Velutina*)	G	Planophil	-10.7	-11.7	-1.0	-11.2
Average of all Planophil Trees			**-13.3**	**-12.6**	**.7**	**-13.0**
Standard Deviation of All Planophil Trees			**2.7**	**2.6**	**1.5**	**2.5**
5. Pin Oak (*Quercus Palustris*)	M	Erectophil	-8.1	-7.5	-1.6	-7.8
6. Eastern Cottonwood (*Populus Deltoides*)	E	Erectophil	-6.5	-8.6	-2.1	-7.6
7. Pin Oak (*Quercus Palustris*)	F	Erectophil	-6.7	-8.2	-1.5	-7.5
8. Weeping Willow (*Salix Babylonica*)	I	Erectophil	-3.9	-5.1	-1.2	-4.5
Average of all Erectophil Trees			**-6.3**	**-7.4**	**-1.1**	**6.9**
Standard Deviation of All Erectophil Trees			**1.8**	**1.6**	**1.2**	**1.6**

* From [9].

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(3) Millimeter Backscattering from Snow

MIRSL has also measured the 215 GHz NRCS of snow packs during the 1987–88 winter season at VV, HH, HV and VH polarizations. Concurrent ground truth measurements of snow surface roughness, moisture content, density, hardness, particle size and grain types were also made. The results of this study are summarized in [3], which is listed in 4C.

The NRCS of 16 different snow packs were measured between 18 December 1987 and 15 February 1988. Typical data are shown in Fig. 2 for measurements made on 6 February, 1988. In general, the like–pol NRCS decreases as a function of incidence angle from a maximum of +5 dB $(m^2 \cdot m^{-2})$ for dry snow at 20° incidence angle to -28 dB $(m^2 \cdot m^{-2})$ for wet snow at 83° incidence angle. The mean depolarization ratio varies from -10 dB to -5 dB, depending on snow conditions.

Of all the snow surface truth parameters measured, snow wetness appears to have the most important effect on the measured results. For example, the NRCS of like–pol measurements drops 5 to 7 dB when the volumetric moisture of the top layer of a snow pack increases from .15% on day 11 to 1.3% on day 12. This agrees with backscatter measurements made by others at lower millimeter frequencies.
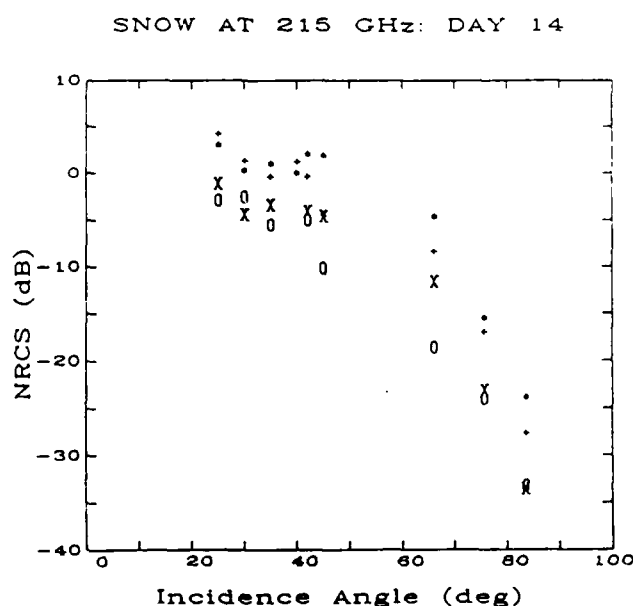
SNOW AT 215 GHz: DAY 14

NRCS (dB) vs Incidence Angle (deg)

Fig. 2   NRCS of snow vs. incidence angle for VV(+), HH(*), VH(x) and HV(o) polarizations measured on 6 February 1988, Amherst, MA. (from [3])

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(4) Modelling of Natural Surfaces for NRCS

The MIRSL has also developed simple models that, to a first order, agree with the measurements described in 4B(2) and 4B(3), above. A phenomenological model based on geometrical optics is given in [2], which predicts the NRCS of deciduous trees as a function of leaf coverage, and time during the foliation period. A more complex computer simulation, made of deciduous trees has also been developed [4], which correctly predicts the effects that leaf orientation has on the normalized backscatter cross section of trees. We observe that the NRCS of Phanophil and Erectophil trees differs substantially with the incidence angle that the millimeter wave impinges on the tree.

C. PUBLICATIONS AND REPORTS RESULTING FROM RESEARCH

1. McIntosh, R.E., Narayanan, R.M., Mead, J.B. and Schaubert, D.H., "Design and Performance of a 215 GHz Pulsed Radar System," IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-36, No. 6, pp, 994-1001, June 1988.

2. Narayanan, R.M., Borel, C.C. and McIntosh, R.E., "Radar Backscatter Characteristics of Trees at 215 GHz," IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-26, No. 3, pp. 217-228, May 1988.

3. Narayanan, R.M. and McIntosh, R.E., "Millimeter-wave Backscatter Characteristics of Multi-layered Snow Surfaces," submitted to the IEEE Transactions on Antennas and Propagation, August 1988, 25 pp + 8 figures, (copy forwarded to ARO September 1988).

4. Borel, C.C. and McIntosh, R.E., "A Simulation of Millimeter Wave Backscattering from Trees," submitted to the IEEE Transactions on Antennas and Propagation, September 1988, 25 pp + 15 figures, (copy forwarded to ARO, September 1988).

5. Mead, J.B., McIntosh, R.E., Vandemark, D. and Swift, C.T., "Remote Sensing of Clouds and Fog with a 1.4 mm Radar," submitted to the Journal of Atmospheric

on Oceanic Technology, October 1988, 7 pp. + 9 figures, (copy forwarded to ARO, October 1988).

6. Borel, C.C., "Models for Backscattering of Millimeter Waves From Vegetation Canopies," Ph.D. Dissertation, Univeristy of Massachusetts, May 1988, 285 pp.

7. Narayanan, R.M., "Measurement and Analysis of Electromagnetic Scattering from Vegetation and Fallen Snow at 215 GHz," Ph.D. Dissertation, Univeristy of Massachusetts, September 1988, 146 pp.

8. Vandemark, D., "Measurements of Atmospheric Liquid Water at 215 GHz," Master's Thesis, September 1988, 89 pp.

9. Chao, Y.F., "RACDA – A Radar Control and Data Acquisition Subsystem for Remote Sensing Applications," Master's Thesis, May 1988, 153 pp.

D. PARTICIPATING SCIENTIFIC PERSONNEL

1. Robert E. McIntosh, Professor and Principal Investigator

2. Calvin T. Swift, Professor and Co–principal Investigator

3. Ram Narayanan, Graduate Student, received Ph.D. degree August 1988, (now a faculty member at the University of Nebraska).

4. Christoph Borel, Graduate Student, received Ph.D. degree June 1988, (now research associate at Los Alamos National Laboratory).

5. James Mead, Ph.D. Graduate Student, expected graduation date, September 1989.

6. Douglas Vandemark, Graduate Student, received M.S. degree, September 1988.

7. Yen–Fang Chao, Graduate Student, received M.S. degree, May 1988.

8. Philip Langlois, Graduate Student, M.S. Candidate.

9. William Teso, Visiting Professor, (regularly employed at the University of Hartford).

10. Chris Ruf, Research Engineer, (now employed at JPL).

5. Bibliography

Not Applicable

6. Appendices

Not Applicable